IMPROVED VACUUM THERMOCOUPLES

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Abstract

Prior construction of Single Junction Vacuum Thermal Convertors (SJTCs) did not consistently produce units with AC-DC differences of a few ppm or less. Four improvement modes have been introduced.

1. Elimination of flaming during the making of the mounting bead
2. Changing of the feed-through posts from Dumet* to Platinum-Iridium.
3. Decrease of the Thomson coefficient by changing from Nickel-Chromium to Evanohm* heater wire.
4. Lowering of the temperature gradient along the heater wire in the vicinity of the thermocouple.

SJTCs can now be constructed with AC-DC differences of less than 0.3 ppm at a high yield.

I. Background

Units with low Reversal Errors (R/E) were selected from a production run, as these were believed to have the best chance for low AC-DC difference [1]. Past attempts to improve SJTCs have been flawed as the manufacturer had no way of measuring AC-DC differences accurately. Feedback from the various agencies that are capable of these measurements was very slow and not well coordinated with the manufacturing process.

II. Flaming

It has been long suspected that flaming of the heater wire could create zones along the heater that were thermoelectrically different, thereby creating Peltier heat and leading to Thomson heat [2]. Cold working or welding on the heater wire could also cause such conditions. The problem was attacked on all fronts at once by using a cold-setting bead to mount the thermocouple as well as using Evanohm wire for the heater plus the addition of cement at the weld of the post and heater. By letting some cement flow onto the heater wire at the posts the R/E could be adjusted and essentially made to be very close to zero. Units built in this manner had to be opened to air after R/E measurement in order to add the compensating cement at the posts and then repumped and resealed. This process was called padding. Such units were submitted to customers in Japan and were reported to have AC-DC differences below 1 ppm [3]. Because of the decapping process required, they were very expensive to manufacture and vulnerable to handling losses. Since there is no direct relationship between R/E and AC-DC difference it was decided to test a batch without padding. The first group, rated at 10-mA (SS283), were tested at CSIRO. Results are listed in Table I.

Quite by chance some standard units were built in a contact form where the heater is welded to the thermocouple. Checking the R/E on two such units it was found that the unit with the thermocouple closer to the center had a higher R/E than the one where the thermocouple was mounted more off-center. A study of equations Widdis developed for R/E [4] led to the conclusion that very large Peltier heat would have to be generated at the posts to cause the amount of R/E measured when the couple was almost exactly centered. It became obvious that only a small amount of Peltier heat generated in the vicinity of the bead would have the same effect. The cold setting cement therefore greatly reduced unwanted Peltier heat and its secondary Thomson heat. Padding was therefore not used in any of the three groups. The 5-mA and 2.5-mA units (SS288 and Special) were tested at NIST and results also tabulated in Table I. Testing on the Special 2.5-mA group presented some problems that may be related to their high thermocouple resistance (80 ohms). The results on the three units are therefore preliminary.

III. Change Dumet to Pt-Ir

Repeated attempts to use Dumet feed-throughs in place of Platinum-Iridium were made to save cost. Each attempt yielded R/E's that were consistently larger with Dumet than with Platinum-Iridium. Dumet is an alloy of Nickel and Iron that is copper-clad in order to make the overall expansion coefficient very close to that of glass. When it is spotwelded to a complex alloy like Evanohm, it seems the weld composition has enough thermoelectric variation from unit to unit to cause more problems than with the Platinum-Iridium. Very low R/E is still obtainable using Dumet but not in a predictable manner. Low R/E units would have to be furnished by selection as in the past.

*Certain trade names are mentioned in the text to adequately specify the procedure and equipment used. In no case does such identification imply recommendation or endorsement, nor does it imply the products are necessarily the best for the purpose.

† Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology; not subject to copywrite in the United States.

IV Change Ni-Cr Heater to Evanohm

Information on the Thomson coefficient of Evanohm is difficult to find, but the overall impression seems to be that it is lower than Ni-Cr. Evanohm does not seem to have the ability to withstand as high a temperature overload as Ni-Cr.

V. Lower Temp. Gradient along Heater

Studies by Levinson [5] on a computer model indicated that matching the heater wire size to the thermocouple wire size would produce maximum heater wire temperature at or near the thermocouple. This should provide two benefits:

a. lower Thomson heat as the slope is less

b. higher output emf.

Higher output has been well demonstrated by the Special group. With 2.5-mA through a 90-ohm heater, the output is the same as that for a standard 5-mA unit. Such a unit can be used in a 1/4 volt application where formerly 1/2 volt was required. More work is needed to substantiate a lower Thomson effect, but initial data on three units did indicate they were in a similar class as the SS288 and SS283.

VI Discussion of Results

Data listed in Table I indicates that SJTCs can be constructed in 5-mA and 10-mA ratings with AC-DC differences of less than 0.3 ppm with high yield. Hopefully when tests are completed on the Special 2.5-mA units, they will be of comparable accuracy.

Test results between the SS288 and SS283 were very similar. Computer simulation studies indicate the maximum temperature of the heater wire on the SS288 occurs between the thermocouple and the post and is approximately 300°C while the maximum temperature of the SS 283 occurs at the thermocouple and is approximately 105°C. The spread in AC-DC difference on the SS283 was 0.25 ppm while the spread for the SS288 was 0.6 ppm. This holds out the possibility that wire size matching may be an improvement factor but data are insufficient at this time. Construction of units with Ni-Cr heaters and beads of cold-setting cement should be tried to compare them with Evanohm heaters. Units with R/E as high as 0.05% should be evaluated to see if the new cold-setting bead will still yield less than 0.3 ppm AC-DC difference. Continuing investigations of Peltier heat reduction can be done using R/E measurements, but measurements of Thomson heat effects on AC-DC differences would need the continued cooperation of the national laboratories.

References

[1] B.D. Inglis "Errors in ac-dc transfer arising from a dc reversal difference," *Metrologia*, Vol. 17, pp111-117, 1981.

[2] B.D. Inglis "Current-Independent AC-DC Transfer Errors in Single-Junction Thermal Converters," *IEEE Trans. on Instr. and Meas.*, Vol. IM-34, No.2. June 1985.

[3] H. Sasaki et al "Automated Measurement System for Thermal AC-DC Transfer Standards," *CPEM Digest*, pp 58-59, 1992.

[4] F.C. Widdis "The Theory of Peltier and Thomson effects in thermal ac-dc transfer devices," *Proc. Inst. Elec. Eng., Monograph 497m*, pp 328-334, 1962.

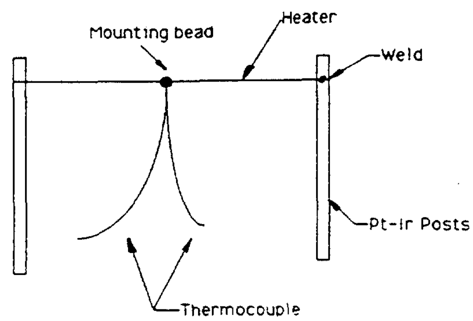
[5] H. Levinson "A Computerized Model of Vacuum Thermocouple Performance," *IEEE Trans. on Instr. and Meas.* Vol. 40, No.2. April 1991.

[6] B.D. Inglis "Standards for AC-DC Transfer," *Metrologia* Vol. 29, No.2. May 1992.

TABLE I

AC-DC DIFFERENCE IN PPM AT 1 kHz

TC No.	SS283 10 mA	SS288 5 mA	Special 2.5 mA	TC No	SS283 10 mA
1	0.2	-0.3	0.4	11	0
2	0.2	-0.3	1.1	12	0
3	0.05	-0.3	0.4	13	0.1
4	0.25	0.0		14	0.15
5	0.1	0.3		15	0.3
6	0.15	0.1		16	0
7	0.05	0.1		17	0.25
8	0.2			18	0.2
9	0			19	0.1
10	0.2			20	0.1



Schematic Sketch of structure